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Contributions to mechanisms for adaptive use of mobile network resources

Olivier Mehani <olivier.mehani@nicta.com.au>

Australian Government
Department of Broadband, Communications and the Digital Economy
Australian Research Council

NICTA Members
NICTA Partners

March 21, 2011

Outline

1. Context, Research Scope and Approach
2. Application-Aware Network and Flow Management
   - Mobile-centric model of multihoming
   - Performance comparison on synthertic scenarios
3. Mobility-Aware Rate Control for Transports
   - Model of TFRC during handovers
   - Mobility-Aware extension to TFRC
4. Network measurement platforms and tools
   - RTMaps
   - OML
5. Towards Thesis Submission

Context, Research Scope and Approach

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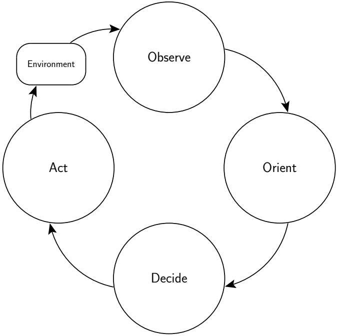
- Mobile devices and vehicular networks
  - Mobile IP(v6)/NEMO
  - multiple access media (MCoA, flow binding)
- Heterogeneous traffic
  - M2I and M2M
  - Infotainment: web, chat, VoIP, VoD
  - Traffic efficiency and safety
  - Variable requirements
    - priority, QoS, adaptability, security
  - High-level (user/application) metrics
    - application quality (*e.g.* QoE), battery use, price
- Varying conditions along the end-to-end (unicast) path
  - Mobility-induced disconnections
  - Improvement/deterioration of characteristics (possibly often)
    - Network metrics: end-to-end throughput, delays, reliability

How to enable mobile communicating peers to make the best use of the network resources when they are available, and degrade gracefully when they are scarce?

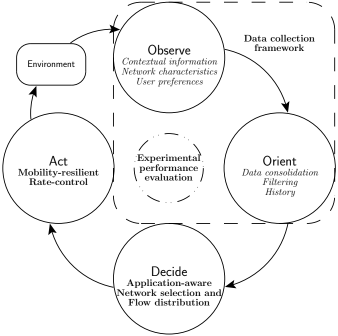
- Approach: OODA loop



Context, Research Scope and Approach

How to enable mobile communicating peers to make the best use of the network resources when they are available, and degrade gracefully when they are scarce?

- Approach: OODA loop
- Contribution axes
  - Optimisation of networks selection and use
  - Improvement of rate control mechanism for mobility
  - Study of measurement platforms and tools



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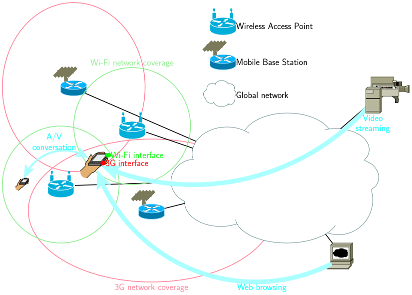
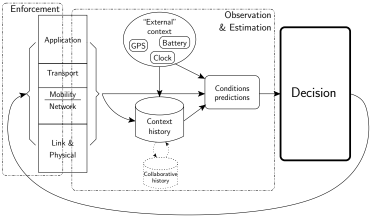
- Multiple networks, interfaces and flows (of different types)
- How to decide
  - which interface(s) to use
  - which network(s) to connect to
  - how to distribute the flows
- to maximise. . . what?
  - raw QoS (*e.g.* goodput or delays)
  - user satisfaction (QoE, *e.g.* application quality or price)



Application-Aware Network and Flow Management

- In-stack cross-layer design too specific
- General move towards vertical control pane alongside the standard network stack
  - IEEE 802.21
  - CALM manager
  - ETSI ITSC management
- No decision mechanisms specified



- Current decisions mechanisms
  - signal strength/SINR
  - expected/predicted network conditions
  - basic prioritising (Wi-Fi with fallback on 3G)
  - no fine grained management of multiple interfaces
- Final goal often ignored
  - actual application quality
  - battery life
  - price
- High level metrics may be better criteria

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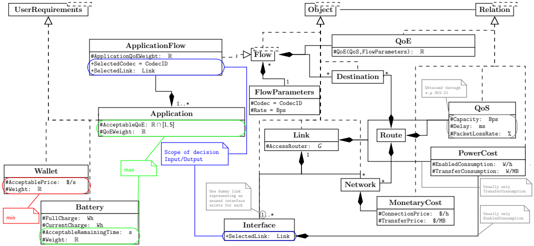
What to consider?

- application flows
  - quality profile
  - parameters (codec, bitrate)
  - user preference
- wireless interfaces
  - power consumption
- networks
  - quality of service
  - power consumption
  - access price

What to decide?

- which interfaces to turn on
- which network to associate them with
- how to distribute flows on the uplinks
- application parameters
- transport parameters



Constraints:

Associations' multiplicity is 1 unless otherwise stated.

$$\sum_{f\in F | f.\text{SelectedLink}=l} \text{FlowParameters}(f.\text{SelectedCodec}).\text{Rate} \le l.\text{Capacity}\ \forall l \in L$$

$$\sum_{f\in F | Network(f.\text{SelectedLink})=n, Destination(f)=d} \text{FlowParameters}(f.\text{SelectedCodec}).\text{Rate} \le n.\text{Capacity}\ \forall n \in N, d \in D$$

Application-Aware Network and Flow Management

- set I of network interfaces
- set N of all available networks $(\mathrm{None} \in N)$
  - $Pr(n), \quad \forall n \in N$ access price
- set $L \subseteq I \times N$ of possible links
  - link association: $\forall i \in I, n \in N \quad l_i = (i, n) \in L$
  - $C(l)$ available capacity
  - $R(l)$ round-trip time
- $Pw(x), \ \forall x \in I \cup L$ induced power consumption
- set F of applications flows
  - type $\forall f \in F \quad t_f \in \{\mathrm{VoIP}, \mathrm{Video}, \mathrm{Web}\}$
  - quality profile $QoE_f = QoE_t(p_f, c_f, d_f)$
    - $c_{\mathrm{req}}(p)$ minimal capacity needed
    - $d_{\mathrm{req}}(p)$ maximal acceptable delay
- $\forall f \in F, \exists i \in I \quad D_f = i$ (flow distribution)

- Select the interfaces to enable and the networks to connect them to, distribute the flows, and select the appropriate parameters for them.

$$\max_{\forall f \in F\, p_f, D_f\ \forall i \in I\, l_i} \left(W_c \sum_{f \in F} QoE_f - W_b \sum_{i \in I} Pw(l_i) - W_p \sum_{i \in I} Pr(l_i) \right) \tag{1}$$

- Two other schemes for comparison

Single network selection

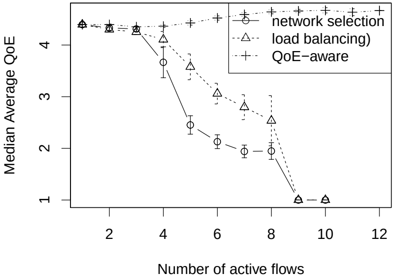
$$\max_{\forall i \in I\, l_i} \left(W_c \sum_{i \in If} C(l_i) \right) \tag{2}$$

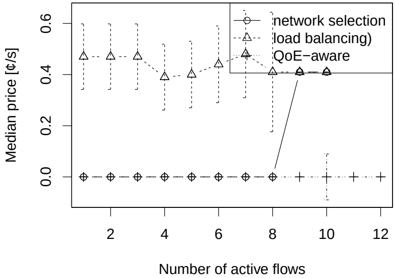
$$\text{s.t.} \begin{cases} \exists i \in I \quad L_i \neq \text{None}, \\ \quad \text{and } \forall j \in I - \{i\} \quad L_j = \text{None}. \end{cases}$$

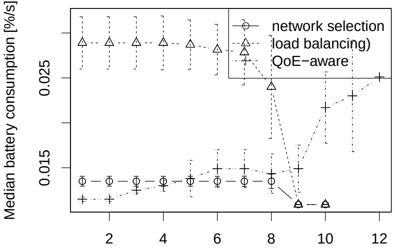
Load balancing on all interfaces

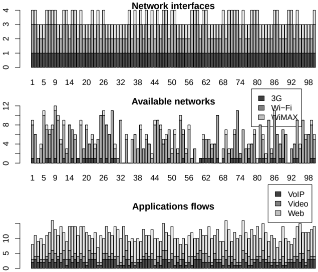
$$\max_{\forall f \in F, \forall i \in I\, l_i} \left(W_c \sum_{i \in If} C(l_i) + W_f F_r \right) \tag{3}$$

$$F_r = \frac{\left(\sum_{i \in I} Lr(i)\right)^2}{|I| \sum_{i \in I} Lr(i)^2}.$$


network selection
load balancing)
QoE−aware
Median Average QoE
1
2
3
4
2
4
6
8
10
12
Number of active flows


network selection
load balancing)
QoE−aware
Median price [¢/s]
0.0
0.2
0.4
0.6
2
4
6
8
10
12
Number of active flows


network selection
load balancing)
QoE−aware
Median battery consumption [%/s]
0.015
0.025
2
4
6
8
10
12


Network interfaces
Available networks
3G
Wi−Fi
WiMAX
Applications flows
VoIP
Video
Web

TODO: sub-optimal algorithm and/or proof that the constraint solver can run in real time

- Conferences
  - Olivier Mehani, Roksana Boreli, and Thierry Ernst. “Context-Adaptive Vehicular Network Optimization”. In: ITST 2009, 9th International Conference on Intelligent Transport Systems Telecommunications. Oct. 2009, pp. 186–191. ISBN: 1-4244-1178-5
- Planned submissions
  - LCN 2011 (March 2011; editorial changes needed): Optimal bounds of the approach
  - CP 2011 (April 2011; in writing): Constraint programming and modelling
  - Expected: Global paper with sub-optimal algorithm to near the derived bounds

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Mobility-Aware Rate Control for Transports

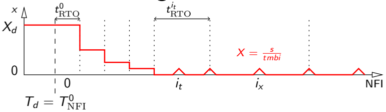
Problem: classical congestion control assumptions broken by mobility

- TCP-Friendly Rate Control (TFRC):
  - rate-based congestion control mechanism
    - needs packets losses p and RTT R
    - $X_{\mathrm{Bps}}(p, R) = \dfrac{s}{R\sqrt{\frac{4p}{3}} + t_{\mathrm{RTO}}\sqrt{\frac{27p}{8}}\,p(1+32p^2)}$
  - TCP-fair congestion control
  - rate-based $\leftarrow$ more adapted to real-time streaming
  - usable with Datagram Congestion Control Protocol (DCCP)
    - unreliable datagrams
    - well suited for real-time traffic over shared networks

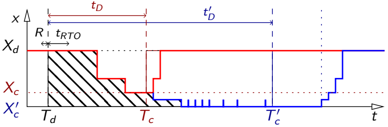
- But
  - losses during hand-off period force a rate reduction

  - poor adaptability to now network characteristics
- How much resources are wasted?
- How not to?

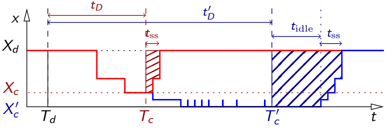
- Evolution of the sending rate and the RTO



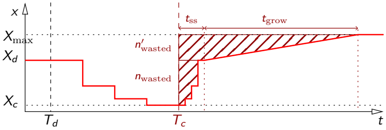
- Number of lost packets over the disconnected period



- Amount of "wasted" bandwidth upon reconnection



- Additional "wasted" bandwidth on higher capacity networks



from \ to	UMTS	802.16	802.11 b	802.11 g
Packet losses				
UMTS	306	236	226	224
802.16	2760	2614	2614	2614
802.11b	1080	1078	1078	1078
802.11g	2909	2907	2907	2907
Unused bandwidth [500 B packets]				
UMTS	0	82938	263	109541
802.16	0	471	155	1029
802.11b	0	0	1085	54674
802.11g	0	0	0	4699

▸ Compare to simulation results

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Related work: Freeze-TCP can temporarily suspend a TCP connection

- in case of predictable disconnections on the receiving end
- rate restored to previous value when connectivity is back

Additional features: better support for mobility handoffs

sender-based freezing: to account for mobile senders

slow-start-like probing: for better capacity along the new path

Freeze-DCCP/TFRC mechanism

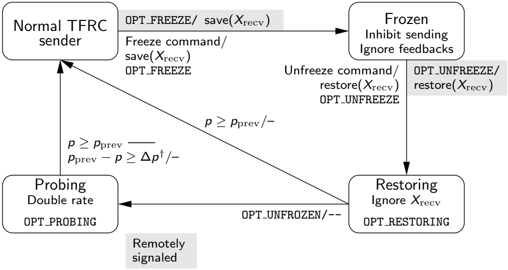
tight cooperation: between the sender and the receiver using DCCP-level options

new states: to support the unfreezing phase:

1. restoration of the rate or fallback to the newly computed value
2. probing the path for a higher capacity

Mobility-Aware Rate Control for Transports

Mobility-Aware extension to TFRC: Additional states and options needed to support freezing

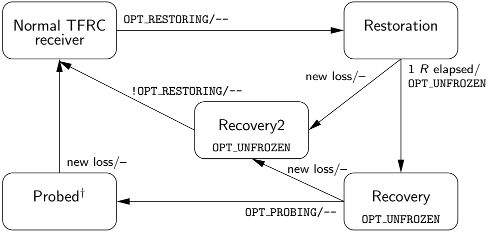


Sender

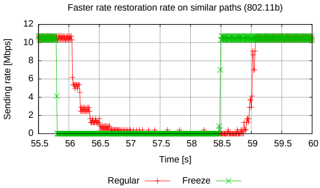
Drives the restoration process

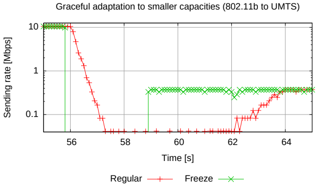
Receiver

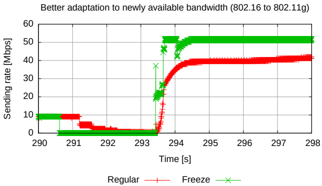
Ensures synchronisation



†When a packet is lost, the receiver computes and reports a p equivalent to the currently observed X_{recv}.







from \ to	UMTS	802.16	802.11 b	802.11 g
Packet losses (DCCP/TFRC only)				
UMTS	253.3	269.8	273.6	275.4
802.16	1732.3	1734.6	1734.6	1734.6
802.11b	856	855.5	855.3	855.3
802.11g	2470.9	2470.4	2470.2	2470.1
Unused bandwidth [500 B packets]				
UMTS	50.5	54018.05	2209.5	92156.1
	13.4	3607.9	9342.75	89328.6
802.16	12.45	1827.95	603.05	4185.75
	5	591.15	150.9	1520.35
802.11b	150.45	28314	2101.75	57970.65
	0	15278	47.45	1045.05
802.11g	42.5	2104.3	943.4	4313
	0	7172.75	46.5	188.45

Compare to analytical predictions

- Conferences
  - Olivier Mehani and Roksana Boreli. “Adapting TFRC to Mobile Networks with Frequent Disconnections”. In: CoNEXT 2008, 4th ACM International Conference on emerging Networking EXperiments and Technologies. Dec. 2008. ISBN: 978-1-60558-210-8. DOI: 10.1145/1544012.1544049
  - Olivier Mehani, Roksana Boreli, and Thierry Ernst. “Analysis of TFRC in Disconnected Scenarios and Performance Improvements with Freeze-DCCP”. In: MobiArch 2009, 4th International Workshop on Mobility in the Evolving Internet Architecture. June 2009. ISBN: 978-1-60558-688-5/09/06
  - Olivier Mehani et al. “Mobile Multimedia Streaming Improvements with Freeze-DCCP”. In: MobiCom 2010, 16th Annual International Conference on Mobile Computing and Networking, Demonstration Session. Sept. 2010
- Software
  - *ns*-2 and Linux 2.6 implementations of Freeze-DCCP/TFRC
  - *ns*-2 and Linux 2.6 implementations of Freeze-TCP

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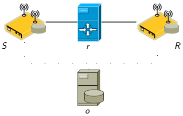
Network measurement platforms and tools

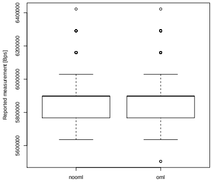
- How to provide an environment capable of dealing with mobile and vehicular network experiment?
- Network measurements needed at several steps
  - Design: of new solutions based on observations
  - Monitoring: of the world in a feedback loop (*e.g.* OODA) to the prototype
  - Experimental performance evaluation: of the proposal
- Mobile/ITS network measurements not trivial
  - many variables, quite a few uncontrollable
  - multiple specific tools with different incompatible outputs
  - results scattered accross experimental machines
- Requirements for network measurement tools
  - generic: multiple different experiments
  - validated: confidence in the measurements
  - extensible: monitor as many variables as possible

- Candidate: RTMaps
  - Rapid prototyping tool
  - Unified timestamped databases (text-based)
  - Host synchronisation over the network
  - Already used for the rest of the in-car infrastructure
- PCap.pck
  - libpcap-based RTMaps packet capture component
  - capture packets locally or forwarded by a router
  - can't keep up with 100 Mbps traffic (loses some measurements)
- Other issues
  - Need to reimplement all measurements systems from scratch
  - Resource intensive
  - Proprietary software: licensing issues, lack of portability

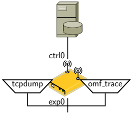
- Candidate: OML
  - C library
  - Unified output format (SQL databases)
  - Timing as accurate as host computer (GPS can give sub-second plecision)
  - Instrumentation of already existing applications
- Intrumented Iperf network testing tool, and others
- More adequate for the purpose
  - No need to reimplement measurement systems
  - More easily deployed
  - Ligtweight
  - Portable

- Need to characterise the precision and accuracy of OML, as well as pontential impact on instrumented applications
- Two starting point cases
  - Network testing with Iperf





    - ANOVA: $F = 0.0016$, $p = 0.9683$, no statistically significant difference
  - Network observation with libpcap



    - TODO

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- Conferences and journal
  - IFIP Performance 2011 (April 2011; experimental work in progress): OML as a high performance measurement library
  - Contributed to journals and conferences
    - Manabu Tsukada, Olivier Mehani, and Thierry Ernst. "Simultaneous Usage of NEMO and MANET for Vehicular Communication". In: TridentCom 2008, 4th International Conference on Testbeds and Research Infrastructures for the Development of Networks & Communities. Mar. 2008. ISBN: 978-963-9799-24-0
    - José Santa et al. "Assessment of VANET Multi-hop Routing over an Experimental Platform". In: International Journal of Internet Protocol Technology 4.3 (Sept. 2009), pp. 158–172. ISSN: 1743-8209. DOI: 10.1504/IJIPT.2009.028655
    - Manabu Tsukada et al. "Design and Experimental Evaluation of a Vehicular Network Based on NEMO and MANET". In: EURASIP Journal on Advances in Signal Processing 2010 (Sept. 2010), pp. 1–18. DOI: 10.1155/2010/656407
- Software
  - RTMaps network monitoring package
  - OML-enabled IPerf, WiMAX (Unwired) monitor
  - Contributions to the OML codebase

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Towards Thesis Submission

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Courses completion:

Advanced Networking (TELE9756) 6 UNSW credits, 33 contact hours, assessment result: 93%

Nicta Short Courses 2 UNSW credits and 21 contact hours each,

- Network Simulation, assessment result: 95%
- Network Analysis, assessment result: 100%

Security Engineering (COMP9441) 6 UNSW credits, 60 contact hours, assessment result: 83%

Engineering Postgraduate Research (GSEO9400) 3 UNSW credits, 21 contact hours

Universities requirements:

ENSMP 155/60 hours ✓

UNSW 19/18 credits ✓

Towards Thesis Submission

Last strand of road

- Thesis redaction completion

Chapter	Completion	Status
Introduction	90%	full draft
Context/SotA	55%	almost complete draft
Application-Aware Management	25%	paper drafts
Mobility-Aware Transport	75%	journal draft
Measurement framework	0%	
Conclusion	0%	

- Roadmap

March	OML evaluation
April	CP paper
May–August	dedicated writing
September	**Submission**